1938

Bulletin 692 April 1938

# The Silver-Scurf Disease of Potatoes

O. D. Burke

IMPERIAL MYCOLOGICAL
12 OCT 1939
INSTITUTE

Published by the
Cornell University Agricultural Experiment Station
Ithaca, New York

Received for publication December 13, 1937

CONTENTS


PAGE

The suscept ..... 3
Plants affected ..... 3
Parts affected ..... 3
Varietal susceptibility ..... 4
The disease ..... 4
Names ..... 4
History and range ..... 5
Importance ..... 5
Symptomatology ..... 7
Morphologic symptoms ..... 7
Signs ..... 7
Histologic symptoms ..... 7
Etiology ..... 10
Name, history, and classification of the pathogene ..... 10
Pathogenicity ..... 11
Morphology of *Spondylocladium atrovirens* ..... 12
Cultural studies ..... 14
Humidity ..... 14
Temperature relationships ..... 16
Reaction of the medium ..... 16
Life history ..... 17
Primary cycles ..... 17
Pathogenesis ..... 18
Saprogenesis ..... 19
Secondary cycles ..... 19
Epiphytology ..... 20
Light ..... 20
Temperature ..... 20
Humidity ..... 23
Control ..... 26
Exclusion ..... 26
Seed treatment ..... 26
Soil treatment ..... 27
Protection ..... 27
Immunization ..... 27
Summary ..... 28
References ..... 28

# THE SILVER-SCURF DISEASE OF POTATOES[1]

O. D. Burke

Potato-growers on the muck lands near Williamson, New York, have found silver scurf causing considerable disfigurement of tubers following the storage period. This condition in the spring of 1933 forced some of the growers of certified seed to sell their stock for table use at a lower price than could have been obtained for seed potatoes. Therefore, at the request of these growers, an investigation of the effects of certain environmental factors during storage was started. For two years a study was made also of the occurrence of the disease in the field, and the growth of the causal organism under laboratory conditions.

## THE SUSCEPT

### PLANTS AFFECTED

No reports of the occurrence of silver scurf on other suscepts than the potato are found in the literature. Attempts at inoculation of sweet potatoes, turnips, beets, parsnips, and carrots have been unsuccessful when the mature parts were kept in moist chambers and sprayed with a spore suspension of the fungus. Mycelium used as inoculum likewise failed to cause the disease. Massee (1909, 1910) reports failure in obtaining lesions by inoculation of parsnips, carrots, and turnips.

### PARTS AFFECTED

It is highly probable that the potato is the only plant affected by silver scurf, and that, in nature, mature or nearly mature tubers alone are susceptible.

Schultz (1916) attempted inoculations on the stems, stolons, and roots of the potato plant under field conditions, without success. Small root-observation boxes as described by Dean (1929) were used in the greenhouse by the writer for determination of the susceptible parts of the plant. Many roots, stolons, and tubers have grown against the glass sides, so that observations of inoculated parts have been made up to the death of the vines. Inoculations were made of both wounded and uninjured plant parts. Spore suspensions, applied as drops from a pipette, and bits of mycelium from an agar plate, were used in making inoculations. Invasion was never obtained, although the mycelium grew from the point of attempted inoculation often to a distance of one inch across the young tuber or along the root or stolon. When mature tubers attached to dead vines in the root-observation boxes were inoculated, invasion of the phellem resulted in nine out of ten trials. Schultz (1916) has reported successful inoculations

[1]Also presented to the Faculty of the Graduate School of Cornell University, June 1935, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

Author's acknowledgment. The writer wishes to acknowledge his indebtedness and appreciation to Dr. F. M. Blodgett and Dr. Charles Chupp, of the Department of Plant Pathology at Cornell University, for aid in selecting this problem and for their many helpful suggestions during the course of the work. To Dr. L. M. Massey and Dr. L. Knudson, also of Cornell University, and to Dr. Blodgett, the writer is indebted for critical reading of the manuscript. The photographic work was done by W. R. Fisher, to whom thanks are due.

on young tubers when the vines were pulled up and the tubers washed, inoculated, and returned to the soil, or when the tubers were removed and inoculated in moist chambers.

### VARIETAL SUSCEPTIBILITY

Data on the variation in susceptibility of different varieties of potatoes to silver scurf have been obtained in only a single instance. Counts were taken of the occurrence of the disease on tubers from a variety test conducted by Dr. C. F. Taylor[2] in western New York for the purpose of determining susceptibility to common scab. All of the varieties were white-skinned. Counts were made on tubers selected at random from the plots and brought to Ithaca. The samples were stored at 41° F. until February 6, when the tubers were washed and the incidence of silver scurf was determined. Humidity conditions in the cold storage were such that spores did not form on the lesions, and, accordingly, few new lesions could have occurred.

For the purpose of showing more clearly the amount of the disease present, four grades were set up: clean, showing no disease; slight, showing up to five small spots; moderate, showing from five small spots up to one-fourth of the tuber covered; and severe, having more than one-fourth of the tuber covered by the lesions.

The data from this test, given in table 1, indicate that differences in susceptibility do occur among varieties. Both smooth-skinned and russet varieties were used in the test. The variety White Gold had no clean tubers, while the U.S.D.A. Seedling No. 44537, a heavily russeted variety, had 95 per cent of clean tubers. Some of the smooth-skinned varieties were among those showing the least amount of disease, while some of the russets were among those more heavily diseased.

TABLE 1. SUSCEPTIBILITY OF POTATO VARIETIES TO SILVER SCURF AS INDICATED BY THE PERCENTAGES OF TUBERS IN THE DIFFERENT GRADES*

| Variety | Clean | Slight | Moderate | Severe |
|---|---|---|---|---|
| | Per cent of tubers | | | |
| White Gold | 0.0 | 23.8 | 28.6 | 47.6 |
| White Blossom Cobbler | 14.7 | 58.8 | 20.6 | 5.9 |
| Columbia Russet | 31.6 | 42.1 | 21.0 | 5.3 |
| Irish Cobbler | 36.4 | 59.1 | 4.5 | 0.0 |
| Robson Seedling | 38.5 | 28.5 | 33.0 | 0.0 |
| Netted Gem (Russet Burbank) | 43.8 | 37.5 | 12.5 | 6.2 |
| Rural Russet | 55.0 | 20.0 | 20.0 | 5.0 |
| Number 9 | 66.7 | 33.3 | 0.0 | 0.0 |
| Heavy-Weight | 68.8 | 31.2 | 0.0 | 0.0 |
| Pioneer Rural | 78.9 | 21.1 | 0.0 | 0.0 |
| U. S. D. A. Seedling No. 44537 | 95.2 | 4.8 | 0.0 | 0.0 |

*Observations of the amount of silver scurf present were not made on the seed used in these plots, and so the amount of inoculum may have varied.

## THE DISEASE

### NAMES

A number of names have been used to designate this disease. The names "Fleckenkrankheit" and "Phellomyces-Fäule", used by Frank (1897, 1898), are the first appearing in the literature. Johnson (1903) first used the name "scab", and later "dry rot". Clinton (1908) used the descriptive term "scurf", to which Melhus (1913) prefixed "silver" to make "silver scurf".

[2]Research assistant, Department of Plant Pathology, Cornell University.

The names used by Frank were based on a misconception of the cause of the disease and the extent of the lesions. It is probable that Johnson worked with more than one disease when he used the terms "scab" and "dry rot". Several other diseases of the potato tuber are accurately described by the term "scab". Rotting does not occur in this disease, and so the term "dry rot" is misleading. "Silver scurf" accurately describes the most noticeable symptom, and this name has now come into general use in America. In Germany and Austria the same name seems now favored, since Husz (1934) used "Silberschorf". In France the name "gale argentée" was used by Crépin (1923), who stated that this name means silver scab and that the name should be "tache argentée" which means silver scurf.

## HISTORY AND RANGE

Harz (1871) first reported the disease while he was observing new potatoes in Austria, but did little more than note its presence. Frank (1897, 1898) published papers discussing what he considered a single disease. He was in all probability working with two diseases—silver scurf, and a disease caused by *Colletotrichum atramentarium* which Dickson (1926) has called the "black dot disease". The next mention of the disease was that of Johnson (1903), who attributed to it considerable dry rot in Ireland. Smith and Rea (1903) reported the presence of silver scurf in England in the same year. Clinton (1908) reported the disease in Connecticut, and in the succeeding decade it was reported from widely separated areas in the United States (Melhus, 1913; Bailey, 1914; Rees, 1914; Taubenhaus, 1916). In 1911 the disease made its appearance in Australia, and it is described by Brittlebank (1915) as the most important disease entering Australia in the three-years period from 1911 to 1914. The disease seemed to be widespread in France by 1916 (Crépin, 1923).

At the present time the disease is found wherever potatoes are grown, having been widely distributed from the highly centralized seed-potato-producing areas.

## IMPORTANCE

At harvest time the disease causes only a slight disfigurement (figure 1), and if the tubers are consumed immediately their quality is little, if any, inferior to that of healthy tubers. On improperly stored tubers the disease increases rapidly and causes severe disfigurement and loss of water, so that losses at times may become important. The increasing demands of the market for clean potatoes for table and seed purposes are each year making more conspicuous the toll taken by silver scurf.

Through the courtesy of Dr. F. M. Blodgett,[3] unpublished data from a tuber-defect survey in September 1932 were made available to the writer. Data on silver scurf were taken only on Long Island. It was not observed elsewhere, perhaps because that was the only place covered by the survey where the potatoes had remained in the soil for a considerable period after maturity. In Nassau County fourteen farms were visited, and these showed an average of 12 per cent of all the tubers inspected to be affected with silver scurf. On only two of the farms were the potatoes free from the disease.

[3]Professor of Plant Pathology, Cornell University.

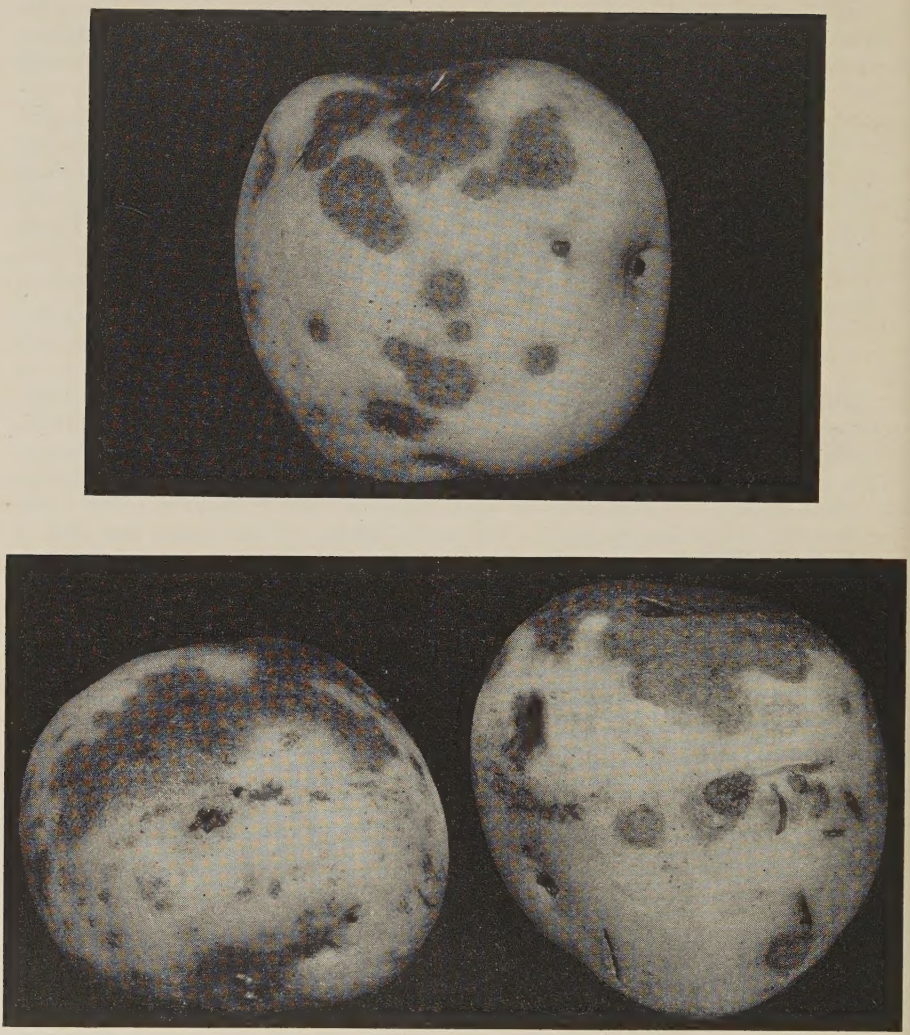

FIGURE 1. TUBERS SHOWING SILVER-SCURF LESIONS
Lesions may be on any part of the tuber, but they often start at the stem end

In Suffolk County thirty-four fields were visited, on which an average of 32 per cent of the tubers showed silver scurf and on only one farm were the potatoes free from the disease. In the latter county one farm showed 94 per cent of the tubers to be affected.

The disease cannot compare in destructiveness with some of the other tuber diseases, such as common scab, late blight, and rhizoctonosis; but the losses on the whole are worthy of notice.

## SYMPTOMATOLOGY

### *Morphologic symptoms*

Morphologic symptoms of the disease are distinctive and should readily separate it from other diseases of the potato tuber. Such confusion as has often occurred in the separation of silver scurf and the black-dot disease (figure 2) has been due to the rather constant association of the two diseases. When either is present by itself, separation is simple. The symptoms as presented here agree rather closely with those given by Schultz (1916). The disease may be confined to small localized spots, or it may cover a considerable part of the tuber surface. In the latter case invasion usually has originated at the stem end, probably from contact with the seed piece which was diseased at planting time. It appears that the spot type of infection is due to penetration of the tissue at a single point, while in the more general type coalescence of many spots has occurred. Whether the involvement is in spots or is general, the progress of the disease is the same, with similar resultant symptoms.

At first the buffy brown (Ridgway, 1912) affected area may be circular or have fimbriated margins, and may present a glazed or a silvery appearance when moistened. At this stage the disease may be easily overlooked unless the tubers are washed. Later stages are characterized by further browning (natal brown of Ridgway) of the surface layers, followed by sloughing-off of the outer cells so that the tuber is protected by an outer covering only a few cells in thickness. After the tubers have been in storage for some time, the surface of the affected areas becomes shriveled and wrinkled (figure 2). Small areas affected by silver scurf are often depressed. When large areas are affected, distinct folding may occur. In the red-skinned varieties the color is completely destroyed. In a large number of cases infection occurs at the stem end, probably due to contact with infected seed pieces. Counts made from the fields during 1933 showed 73 per cent of the infection to be at the stem end, but in the other cases infection occurred at any point on the tuber.

### *Signs*

In the early stages of infection an olivaceous black color (Ridgway, 1912) appears over the affected area. This is the so-called "brown mold stage", and is caused by the production of conidia and conidiophores (figure 3) of the causal organism. In cases of severe infection under storage conditions favorable for sporulation, the entire surface of the tuber may become dull black and sooty in appearance, owing to the numbers of conidia and conidiophores over the surface. The presence of minute black "sclerotia" (figure 2) has often been listed as a sign of the disease, but Taubenhaus (1916) has shown that these are due to the presence of a secondary organism.

### *Histologic symptoms*

Histologic symptoms are easily studied, since the potato tuber lends itself readily to staining and embedding technique. Many sections have been made from material embedded in paraffin, both healthy and diseased tissues being used.

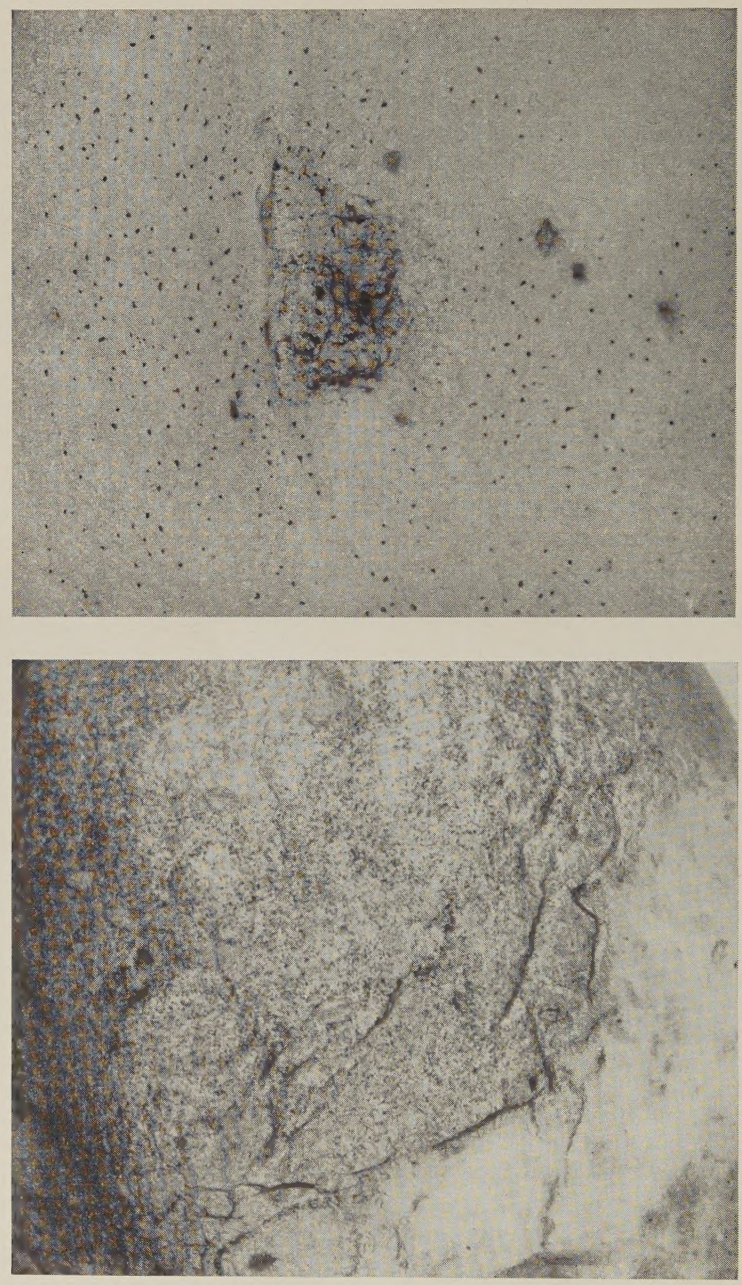

FIGURE 2. SURFACES OF POTATO TUBERS AFFECTED WITH THE BLACK-DOT DISEASE (UPPER PHOTOGRAPH) AND WITH SILVER SCURF (LOWER PHOTOGRAPH). BOTH × 2.5

The minute black "sclerotia" mentioned on pages 7, 10, and 11 are shown in the upper photograph

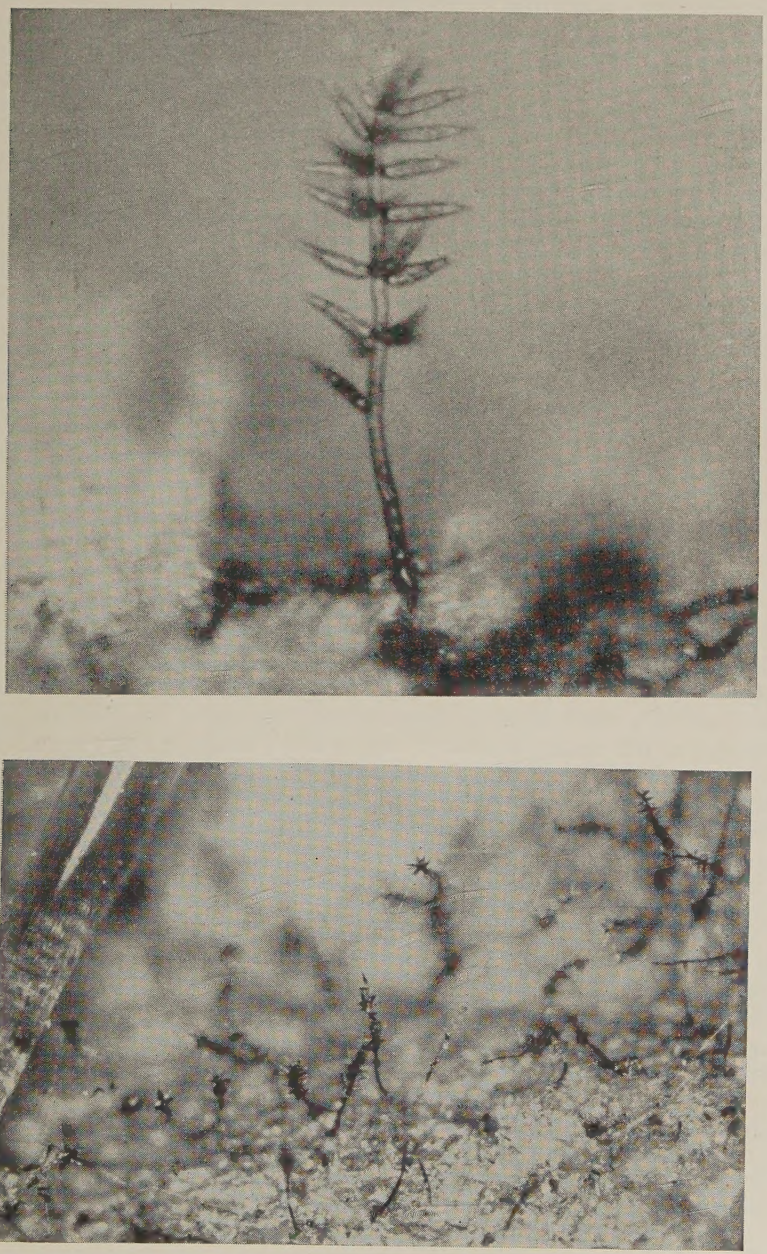

FIGURE 3. MICROPHOTOGRAPHS OF CONIDIOPHORES AND CONIDIA OF SPONDYLOCLADIUM ATROVIRENS ON THE SURFACE OF A POTATO TUBER. UPPER, × 150; LOWER, × 30

Artschwager (1924) has shown that the normal tuber loses its epidermis while it is yet small. A phellogen layer, laid down from the outer parenchyma layers, then proceeds to act as a cork cambium. The number of layers formed is variable, according to the variety and the environment of the growing tuber. Irish Cobbler tubers were used in the sectioning work. Healthy tubers show about nine phellem layers and may have one or two layers below the phellogen; but in most instances the latter are not present or are so irregularly placed as to be difficult to identify definitely. The cells are interlocked and narrow, giving a compact structure to the periderm.

Areas invaded by *Spondylocladium atrovirens* show a variable number of cork layers, according to the progress of the fungus. In several instances in this study, only two layers were present. Invaded areas have fungous mycelium either between the cells or in them. Air spaces are numerous, owing to the action of the fungus in forcing the rigid cells apart to make room for its growth. Since the cells, at least in the outer layers, are non-living when once loosened by the action of a fungus, they are readily sloughed off or else they remain in place with many air pockets between them. The silvery appearance of the tuber surface when wetted is due to the air pockets formed between the cells.

## ETIOLOGY

### *Name, history, and classification of the pathogene*

The pathogene of silver scurf is a fungus, *Spondylocladium atrovirens* Harz, one of the Hyphomycetes of the Fungi Imperfecti. This fungus was first described by Harz in 1871, but was not at that time linked with the disease. Frank (1897, 1898) failed to get pure cultures from diseased tubers, and described a sterile fungus, which he called *Phellomyces sclerotiophorus,* as the causal organism. Appel and Laubert (1907) found conidia of the pathogene and thought they had the fruiting stage of the fungus described by Frank. They gave it the name of *Spondylocladium atrovirens.* Melhus (1913) accepted the name given by Appel and Laubert, as had also Clinton (1908).

Taubenhaus (1916) seems to have been the first worker to use pure-culture technique in determining the identity of the fungus. He showed the presence of two organisms in the lesions, finding both in some 99 per cent of the isolations attempted. A slow-growing fungus, *Spondylocladium atrovirens* Harz, was proved capable of causing silver scurf, while the more rapidly growing fungus, *Colletotrichum atramentarium* Taub., which produced minute black bodies bearing spines, was unable to cause disease on the mature tubers. This secondary organism was capable of going deeper into the tuber than did the Spondylocladium. Taubenhaus called the black bodies "sclerotia". Husz (1934) repeated the work done by Taubenhaus, but concluded that both of the fungi present are capable of causing diseases of potatoes: that *S. atrovirens* is the cause of silver scurf, and that *C. atramentarium* causes a disease of the stem and other parts of the plants as well as of the tubers. The black sclerotia of Taubenhaus, however, were called by Husz "micro-stromata".

*Pathogenicity*

The work of Taubenhaus and of Husz has been repeated here during the past two winters. Both *Spondylocladium atrovirens* and *Colletotrichum atramentarium* have been obtained in isolations from silver-scurf lesions. It has been possible to obtain pure cultures of *S. atrovirens* from the majority of the lesions without contaminations by the Colletotrichum. *C. atramentarium* has been obtained only when the black bodies (figure 2) mentioned by Taubenhaus have been plainly discernible on the surface of the lesion. Isolations have been made either by grinding a bit of the diseased tissue in a sterile mortar and then using dilution plate methods, or by making tissue plantings from the diseased spots. Sterilization of the pieces of tissue for ten minutes in calcium-hypochlorite solution, 10 grams to 140 cc of water (Wilson, 1915), has been found satisfactory for killing the ordinary contaminants on the surface without harming the organisms within the tissue. Cultures from single spores have been used for inoculation work.

Silver scurf has been caused readily by spraying tubers with a spore suspension of *S. atrovirens* and incubating the tubers in moist chambers at 24° C. for a period of two weeks. Recovery of the organism has always given pure cultures of *S. atrovirens*. When *C. atramentarium* has been used as inoculum in the same manner, no lesions of the type produced in silver scurf have been found. Checks sprayed with water and kept in the same conditions, likewise have failed to develop silver scurf.

The pathogenicity of *S. atrovirens* and of *C. atramentarium* has been tested also by growing plants in soil infested with both organisms. Muck soil in pots was steamed at 25 pounds pressure for two hours. The organism used to infest the soil was cultured on sterilized wheat; wheat three parts and water two parts have been found to give good growth of both organisms. The soil in four pots was left uninfested to serve as checks; four pots contained soil to which wheat carrying the growth of *S. atrovirens* was added; four pots contained soil infested with *C. atramentarium*; and four pots contained soil with a mixture of the two organisms. In addition, four pots were planted with seed pieces affected with silver scurf. All other seed pieces were disease-free. Irish Cobbler potatoes were used in these tests. This experiment was repeated, and the data given in table 2 are for both trials.

TABLE 2. COMPARISON OF AMOUNT OF SILVER SCURF OBTAINED UNDER GREENHOUSE CONDITIONS WHEN STERILIZED SOIL WAS INFESTED WITH SPONDYLOCLADIUM ATROVIRENS AND COLLETOTRICHUM ATRAMENTARIUM

| Kinds of inocula added to soil | Number of tubers harvested | Number of diseased tubers | Total number of lesions | Type of lesions |
|---|---|---|---|---|
| Wheat culture of *S. atrovirens* | 28 | 25 | 31 | Silver scurf |
| Wheat culture of *C. atramentarium* | 27 | 12 | 14 | Black dot |
| *S. atrovirens* + *C. atramentarium* | 31 | 29 | 37 | Silver scurf and black dot |
| Diseased seed-pieces* | 31 | 15 | 15 | Silver scurf |
| Nothing added to soil | 32 | 0 | 0 | |

*Carrying silver-scurf lesions.

Isolations from diseased tubers harvested from this experiment uniformly showed the organism that had been used to infest the soil. Silver-

scurf lesions were obtained on tubers from soil infested with S. *atrovirens*. *C. atramentarium* showed the ability to cause lesions of the type found in the black-dot disease (figure 2), but not silver scurf. When a mixture of both organisms was added to the soil, the lesions were typical of silver scurf but had in addition the minute black bodies found in the black-dot disease. Both organisms could be recovered from these lesions. Diseased seed-pieces did not give as high a percentage of tubers infected with *S. atrovirens* as did the infested soil.

### *Morphology of Spondylocladium atrovirens*

The morphology of *Spondylocladium atrovirens* was studied in culture, and a comparison of the findings was made with Lindau's descriptions as given in Engler and Prantl's "Die Natürlichen Pflanzenfamilien" (Lindau, 1900). According to Lindau, *S. atrovirens,* one of the black molds, is classified as belonging to the order Hyphomycetes of the Fungi Imperfecti, family Dematiaceae, section Phragmosporeae, subfamily Acrothecieae. The genus Spondylocladium is characterized by its dark multiseptate conidiophores which bear many-celled conidia in indefinite whorls.

The fungus fruits in culture, although not so prolifically as it does on the tubers kept in moist chambers. Conidia are produced in abundance on green beans used as a cultural medium. When plantings are made on agar plates the first growth can be noted macroscopically in five days, but it is not until the tenth to twelfth day that conidia can be found. The fungus is typically slow-growing, both in the outer layers of the tuber and on agar cultures.

Spore measurements have confirmed Schultz's (1916) statement as to the great variability in size of the spores. As much variation was found in the size of spores from the tuber as in those produced in culture (figures 3 and 4). The spores ranged in size from 7.5 to 12μ in width and from 36 to 61μ in length. The largest number of spores measured 8 by 35–40μ and were 5- to 7-septate. The number of septa in the spores is not constant, as few as two septa often occurring and as many as nine being occasionally observed.

The spores germinate readily when placed in a drop of water on a glass slide. On a series of six slides counted, 92 per cent germination was found. On each slide 50 spores were counted, making a total of 300 spores in the test. Germination sometimes occurred in ten hours, but the maximum had not been reached until twenty-four hours had elapsed. The spores generally germinate from the small end (figure 4), but often additional germ tubes are put out from other cells.

The conidiophores are multicellular (figure 4), and range in length from 150 to 375μ. The thickness is fairly constant at 7 to 8μ but is slightly greater at the base, which is rounded. Spores are borne in whorls at the distal end of the cells comprising the conidiophore. The larger whorls are about midway of the conidiophore, although spores are produced near each septum up to the apex. The first few basal cells usually do not produce spores.

The mycelium is at first hyaline, and up to the time of spore formation it is much lighter in color than the spores; later it becomes dark brown and appears grayish black in mass. Two types of mycelium are common, both

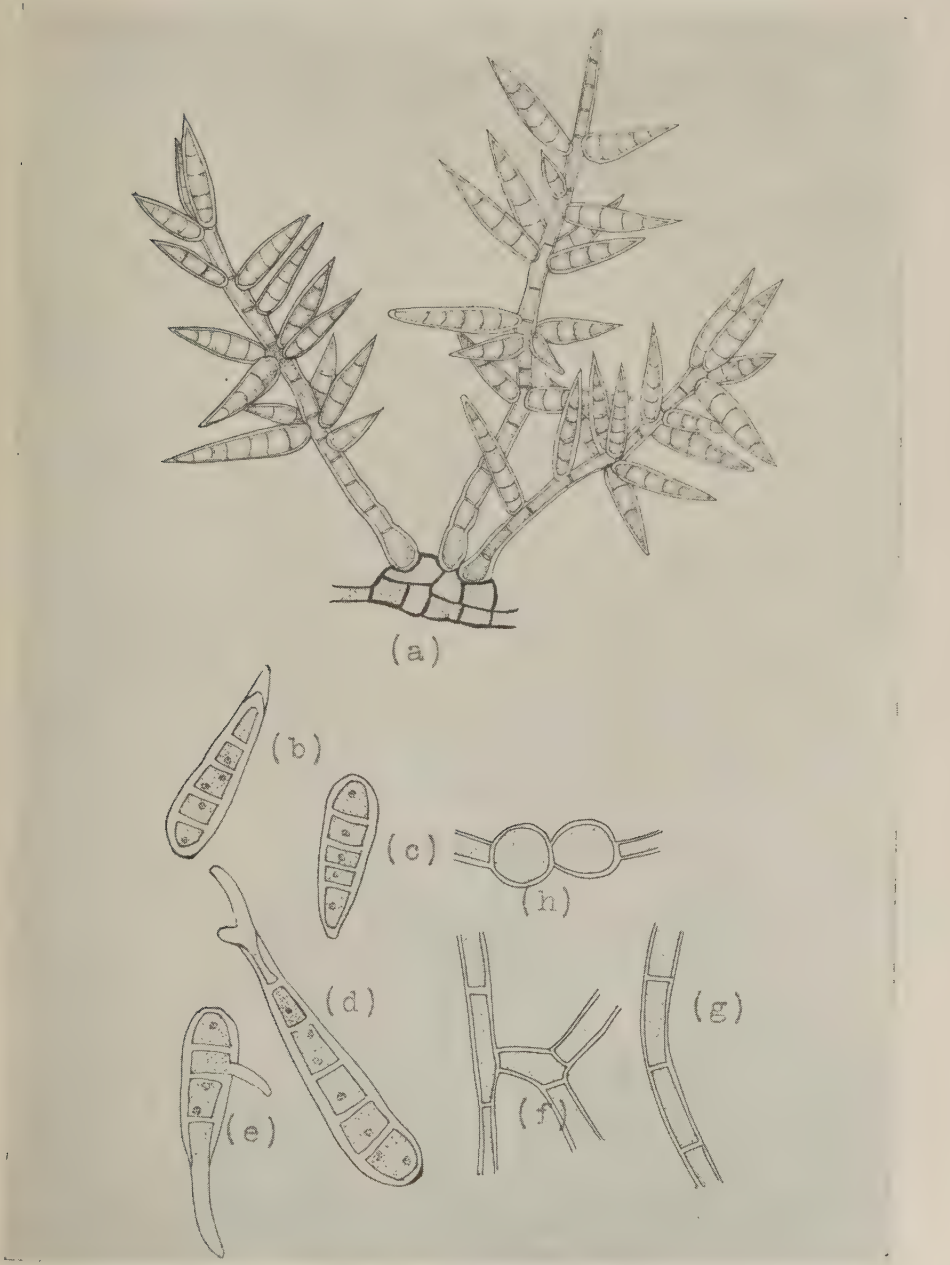


FIGURE 4. SPONDYLOCLADIUM ATROVIRENS

a, Conidiophores and conidia from tuber; b and c, conidia; d and e, germinating conidia; f, g, and h, portions of mycelium from an agar plate.

All drawings made with the aid of a camera lucida. a, × approximately 260; b, c, d, e, f, g, and h, × approximately 575

in culture and in tuber lesions: the mycelium may be straight, septate, and brown in color, or it may be composed of many round to barrel-shaped cells very dark in color (figure 4). On the tuber the globular cells of the latter type of mycelium mass together in a gnarl, in appearance like minute sclerotia. In culture the same knots are formed, but they are more loosely associated than on the tuber. The conidiophores arise from the rounded cells, but in rare instances a spore has been observed borne on the end of a strand of the straight type of mycelium.

## *Cultural studies*

### *Humidity*

Humidity of the atmosphere and of the substrate has been studied, in respect both to spore germination and to linear growth of the fungus. Sulfuric acid of known strength (Stevens, 1916) was used to control the atmospheric humidity about the medium or the spores.

Spore germination was observed under controlled humidity conditions at a temperature of 24° C., by using micro slide rings of glass cemented to glass slides. Five humidities were used—100, 99, 98.2, 97, and 96.2 per cent—these being produced by placing small amounts of sulfuric-acid solutions in the bottom of the cells. No means of testing the actual relative humidities obtained were available, but care was taken that the specific gravities of the acids used were accurate. Spores were dusted on clean dry cover slips, the slips being carefully inverted over the micro slide rings so as not to dislodge the spores, and cemented in place with vaseline. Readings were taken at the end of twenty-four hours, 50 spores being taken as a sample of the spores present on any one slide. The experiment was repeated in duplicate three times. It was found (table 3) that germination was high when water was placed on the cover slip, but that it dropped off rapidly when no free water was supplied.

TABLE 3. COMPARISON OF GERMINATION OF SPORES IN WATER AND WHEN DRY, OVER DIFFERENT CONCENTRATIONS OF SULFURIC ACID

| Specific gravity of solution used | Theoretical relative humidity (per cent) | Per cent of spores germinated |
|---|---|---|
| Check (spores in drops of water) | ..... | 92 |
| 1.00 sp. gr. | 100.0 | 24 |
| 1.02 | 99.1 | 10 |
| 1.04 | 98.2 | 7 |
| 1.06 | 96.9 | 0 |
| 1.07 | 96.2 | 0 |

Although germination was low when free water was absent, conidia were so numerous that even the low percentages of germination in the absence of water were sufficient for rapid spread of the disease under storage conditions in which the humidity was high.

The effect of relative humidity on growth of the fungus in culture was determined by using apparatus and methods described by Shaw (1935). The apparatus consisted of a wood base into which were fitted the lower halves of deep petri dishes so that they were flush with the surface. The medium for growth was poured into the covers and allowed to solidify, and the covers were then inverted over the bottoms. The edges of the covers

rested on the wood and were sealed into place with vaseline. It was found that few contaminations occurred if the agar, after being poured, was protected by a piece of sterile paper until it was placed in position on the wood base. A battery of eight petri dishes was used, so that four controlled atmospheres were kept in duplicate in each experiment. At no time was a contaminated plate allowed to remain in the experiment. Potato-dextrose agar was used as a growth medium. Exactly 75 cc of the acid was introduced into each petri dish. It was carefully pipetted off at the end of each week, and measured. If 15 cc of agar was used in each culture dish, four weeks was sufficient for equilibrium to be established between the agar and the atmosphere. Equilibrium was considered reached when the same amount of acid was removed as was introduced. Small bits of mycelium to which no agar adhered were transferred to the plates, care being taken to use the same amount of mycelium in each dish. Planting was done at the end of the fourth week after the dishes were poured.

The preliminary run was with 100, 98.2, 95.6, and 89.9 per cent relative humidities. No growth occurred at the two lower humidities; there was good growth at the two high humidities, with the better growth at 98.2 per cent.

In the remainder of the humidity work, 95.6 per cent was used as the lowest humidity. Growth was measured as diameter of the cultures in millimeters. The experiment was repeated three times. Comparable data were obtained, so that only the data obtained from the experiment started on November 11, 1933, are presented (table 4).

TABLE 4. DIAMETER, IN MILLIMETERS, OF CULTURES OF SPONDYLOCLADIUM ATROVIRENS, UNDER CONDITIONS IN WHICH THE RELATIVE HUMIDITY WAS CONTROLLED AT 24° C.

| Specific gravity of the acid | Theoretical relative humidity (per cent) | Number of days after planting | | | | | |
|---|---|---|---|---|---|---|---|
| | | 6 | 8 | 10 | 12 | 14 | 16 |
| | | Diameter of cultures (millimeters) | | | | | |
| 1.00 | 100.0 | 6<br>6 | 10<br>11 | 15<br>15 | 20<br>20 | 26<br>25 | 33<br>32 |
| 1.03 | 98.7 | 6<br>6 | 12<br>11 | 16<br>16 | 22<br>23 | 28<br>28 | 38<br>39 |
| 1.06 | 96.9 | 4<br>4 | 8<br>8 | 9<br>10 | 11<br>11 | 15<br>15 | 18<br>18 |
| 1.08 | 95.6 | 0<br>0 | 0<br>0 | 0<br>0 | 3<br>3 | 4<br>4 | 4<br>5 |

Water loss by the medium was apparent in the last two humidities used. Good growth was obtained at 100 per cent, but slightly better growth when the humidity was lowered a little, at 98.7 per cent. Spore production occurred at all the three higher humidities, but growth was slight at the lowest humidity, with only mycelium of the rounded type being formed. The tendency toward the formation of many rounded cells was noticeable as the humidity was lowered.

*Temperature relationships*

Eleven temperatures ranging from 3° to 33° C. were available for determination of the effect of temperature on the growth of the fungus in culture. Five plates were kept at each of the temperatures. Planting material consisted of a small bit of agar bearing mycelium of the fungus cut from a rapidly growing petri-dish culture. Care was taken to have all the pieces of agar as near to 1 mm square as was possible. Growth rate was measured as the diameter of the thallus, and was taken at two-days intervals following the first macroscopic evidences of growth. This work showed the optimum temperature for growth to be 24° C., but that temperature was only slightly better than either 21° or 27°. At 6°, 9°, and 30°, the growth was delayed, appearing eight days later than at the other temperatures. No growth occurred at 3° or at 33°.

In the second trial the plates were sealed with a wide rubber band to prevent drying at the higher temperatures, and slight growth was obtained at 33° C.

*Reaction of the medium*

Medium reaction in its relation to growth was determined by Schultz (1916), Fuller's scale being used as an index of acidity. Schultz found the best growth near neutrality.

The writer studied the effect of different hydrogen-ion concentrations on the growth of the fungus in culture. Potato-dextrose agar containing 2 per cent of dextrose, 1.5 per cent of agar, and 400 grams of potatoes to each liter, prepared in the usual manner, was used. One-fifth-molecular LeMotte standard buffer solutions were used to adjust the pH of the medium. The nutritive material for 1 liter of the medium was made up to 800 cc. Of this, 80 cc was introduced into an Erlenmeyer flask for sterilization. The amounts of acid and of alkali used for each pH were then diluted to 20 cc with distilled water, and placed in another Erlenmeyer flask. The two were sterilized separately and then mixed, bringing the total volume up to the liter for which the original materials were intended, and the plates were poured immediately. Three petri dishes were then poured from each 100 cc, and the remainder was used in making acidity determinations. All the pH determinations were made electrometrically, using the glass electrode and checking with quinhydrone when possible. The transfer material consisted of pieces of mycelium and agar 1 mm square, cut from the margin of young cultures of *S. atrovirens*. These were placed in the center of each plate, and growth measurements were made at two-days intervals after macroscopic growth could be observed. Growth was recorded in millimeters, and represented the average of the largest and the smallest diameter.

The data in table 5 show that this fungus is capable of growing through a rather wide pH range, and that it is capable of changing the pH of the medium. The amount of change during a certain time period seems dependent on the amount of growth. As was expected in such a slow-growing fungus, no sharp maximum at which growth was best could be determined, but rather the fungus changed the medium to such an extent that good growth occurred at any pH at which initial growth could be obtained.

TABLE 5. GROWTH OF SPONDYLOCLADIUM ATROVIRENS ON POTATO-DEXTROSE AGAR WHEN THE pH OF THE MEDIUM IS VARIED BY ADDING HCl OR NaOH

| Amount of reagent added (cc) | Original pH of medium | pH at end of trial | pH in part containing fungus | Days after planting: 6 | 8 | 12 | 15 | 24 |
|---|---|---|---|---|---|---|---|---|
| | | | | Diameter of thalli, in millimeters (average of three plates) | | | | |
| NaOH N/5 | | | | | | | | |
| 10 | 9.4 | 9.3 | 7.0 | 0 | 4 | 7 | 13 | 18 |
| 8 | 9.3 | 9.2 | 6.9 | 0 | 6 | 10 | 15 | 25 |
| 6 | 9.1 | 9.0 | 6.7 | 0 | 6 | 12 | 17 | 25 |
| 4 | 8.65 | 8.45 | 6.14 | 3 | 7 | 16 | 21 | 28 |
| 2 | 8.2 | 8.05 | 5.98 | 4 | 13 | 19 | 23 | 35 |
| 1 | 7.8 | 7.54 | 6.31 | 3 | 10 | 16 | 18 | 22 |
| 0.5 | 7.2 | 7.15 | 6.1 | 4 | 15 | 21 | 24 | 36 |
| 0 | 6.63 | 6.59 | 5.6 | 4 | 15 | 21 | 23 | 33 |
| HCl N/5 | | | | | | | | |
| 0.25 | 6.29 | 6.34 | 5.10 | 5 | 10 | 19 | 23 | 32 |
| 0.5 | 5.08 | 6.03 | 5.48 | 4 | 13 | 19 | 24 | 32 |
| 1 | 5.25 | 5.56 | 5.32 | 3 | 10 | 19 | 21 | 28 |
| 2 | 4.78 | 4.83 | 5.10 | 3 | 10 | 16 | 18 | 20 |
| 3 | 4.39 | 4.66 | 4.87 | 3 | 10 | 13 | 16 | 20 |
| 4 | 4.16 | 4.36 | ....* | 3 | 5 | 6 | 7 | 8 |
| 5 | 3.83 | 4.20 | .... | 0 | 0 | 0 | 3 | 4 |
| 6 | 3.51 | 3.71 | .... | 0 | 0 | 0 | 0 | 0 |

*The growth below this pH was too small to permit getting any measure of the pH after the fungus had grown in the medium.

The pH readings for the medium in which the fungus had grown are not entirely accurate, since all the medium removed for the determination necessarily carried some which was not affected by the growth of the fungus. Growth in culture is influenced, at least with *S. atrovirens*, by the changes in pH (table 5) caused by the growth products of the fungus, as much as by the original pH of the medium.

## *Life history*

The literature contains very little information on the life history of *Spondylocladium atrovirens,* except in its relation to the potato tuber.

### *Primary cycles*

The primary cycles have been considered to start at any time during the growth period of the tuber (Schultz, 1916). In the present experiments, inoculations of immature tubers in the root-observation boxes were uniformly unsuccessful. Both bits of agar bearing mycelium of the fungus, and spore suspensions, were used without securing invasion of the tuber tissues. Tubers removed from the vines while small, inoculated, and placed in moist chambers, were longer in showing lesions than were mature tubers, but eventually proved susceptible.

Observations were made in the field[4] to determine the time of the first appearance of silver scurf, by digging tubers at intervals, washing them, and inspecting them for the presence of the disease. Two varieties of potatoes were planted in a replicated Latin-square arrangement so that representative samples could be dug at intervals during the growing season. Plants

[4]Dr. H. S. Cunningham, of the Long Island Vegetable Research Farm, kindly allowed the writer to make observations on potatoes used in nematode work at that station.

were dug from each replication, and the tubers were washed and inspected for silver scurf. There were 100 tubers of Green Mountain and the same number of tubers of Irish Cobbler inspected each week.

Silver-scurf symptoms did not occur until after the vines were dead. The time at which silver scurf developed may have been influenced by the fact that the summer of 1934 was very dry on Long Island. Lateness of infection seemed the rule over Long Island during that summer. Counts were made on tubers being dug for the early market in Nassau County on July 27. On four farms 100 tubers were cleaned and inspected without any silver scurf being found, but three small lesions were found in a 200-tuber sample on a fifth farm. Two of the farms visited showed 12 per cent and 23 per cent, respectively, of silver scurf during September 1932, according to the data obtained by Dr. F. M. Blodgett in a tuber-defect survey mentioned earlier in this paper.

The results of this experiment (table 6) indicate that most of the primary cycles are initiated after the tubers have matured and while they remain in the soil before being harvested.

TABLE 6. NUMBER OF SILVER-SCURF LESIONS OCCURRING ON GREEN MOUNTAIN AND IRISH COBBLER TUBERS DUG AT INTERVALS DURING THE SUMMER OF 1934

| Variety | Date of digging* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | July | | | August | | | | September | | |
| | 14 | 23 | 30 | 6 | 13 | 20 | 27 | 4 | 10 | 17 |
| | Number of silver-scurf lesions | | | | | | | | | |
| Irish Cobbler | 0 | 0 | 0 | 0 | 0 | 3 | 8 | 9 | 27 | 47 |
| Green Mountain | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 25 | 48 |

*The Irish Cobbler vines were for the most part dead on July 23, but the Green Mountain vines remained alive until August 5.

*Pathogenesis.* Inoculation for the primary cycles takes place in the field, and may originate from inoculum on the seed piece, from infected tubers remaining in the soil from the preceding year, or from the fungus living in the soil as a saprophyte. It appears that most of the cases arise from inoculum carried by the seed piece. In 500 infected tubers that were examined, 73 per cent of the lesions had developed from the stem end, either adjoining or near the stolon. A higher percentage of the tubers showed lesions when a large amount of mycelium was added to pots in the greenhouse than when only the seed piece was diseased (table 2, page 11). In cases in which the seed piece was the only source of inoculum, the lesions were all either near the stem end or at points where the tuber came in contact with the seed piece. In no case could it be demonstrated that the stolon was injured by the fungus. In some cases lesion development seemed dependent on the chance nearness of the inoculum.

Either mycelium or spores may cause the lesions, but under artificial conditions more difficulty has been experienced in getting symptoms with mycelium than with spore suspensions. Spores germinate within twenty-four hours, and within forty-eight hours ingress has generally been effected.

Ingress may be directly through a cell of the outer layers, or may be through a lenticel. Ingress has been studied by placing a drop of water containing spores on a tuber, marking the spot with india ink, and later removing the outer layers for examination under the microscope. Examinations have been made both on stained material (cotton blue) and on unstained material. The germ tube remains hyaline until after entrance has been effected; then the color of the mycelium changes rapidly to brown. No holdfast organ has been observed at the point of entrance, although slight enlargement seems to occur in most instances. Penetration may be directly into the cell or may be between cells; in either case the mycelium becomes both inter- and intracellular. No browning nor other evidences of cell disorganization have been observed at the point of entrance, although the cells affected show browning later.

Invasion, as judged macroscopically, ordinarily requires several days; under moist-chamber conditions the average is sixteen days. Schultz (1916) states that at the end of three weeks conidia are produced. The average period observed by the writer has been nearer four weeks after the tissue has been invaded.

Microscopic symptoms, evidenced by slight browning of the affected cells, have been observed at the end of three days. The rate of increase in the size of lesions seems dependent on external factors—that is, on temperature and moisture.

*Saprogenesis.* Saprogenesis has not been studied in detail. Taubenhaus (1916) believes that the major source of inoculum is the saprogenic existence of the fungus in the soil. Attempts to recover the organism from soil in which potatoes infected with silver scurf had been grown, were unsuccessful. The prevalence of fast-growing soil organisms made impossible the recovery of the slow-growing *S. atrovirens.* In a single instance where pots in which diseased potatoes had been grown were allowed to dry for a month and were then replanted with clean seed, the tubers harvested were clean also.

Two types of soil, clay loam and muck, were used here as culture media in which to grow the organism. The soils were steam-sterilized for thirty minutes at 15 pounds pressure in 150-cc Erlenmeyer flasks. Four flasks of each kind of soil were used, one of which was not planted and remained sterile throughout the work. A small bit of agar bearing mycelium was added to the other three flasks of each kind of soil. Four weeks after infestation no growth could be observed on the clay soil, but mycelium could be seen throughout the muck. Isolations from the clay soil gave positive results in one out of ten attempts, while from the muck soil numerous cultures of *S. atrovirens* were obtained. Isolations at later intervals from the clay soil were unsuccessful, but from the muck soil they were successful up to nine months. Growth conditions in the flasks, while not at all comparable with those in the field, do indicate that soils rich in humus are capable of supporting this fungus if environmental conditions are favorable.

### *Secondary cycles*

Secondary cycles may originate in the field from inoculum produced in the primary lesions, but the greater number originate during the storage period. Under conditions of high moisture and warm temperatures in the

storage house, succeeding cycles may follow one another in rapid succession. Most of the loss due to silver scurf arises in this manner.

## EPIPHYTOLOGY

The factors affecting the occurrence of silver scurf under storage conditions are light, temperature, and humidity. All are probably of importance in the field, but no data are available on this subject. From observations, Schultz (1916) concluded that the lower, damp parts of a field are more likely to have severe outbreaks of the disease than are the higher parts.

### *Light*

Light has a decided effect on the direction of growth of *S. atrovirens*. Schultz demonstrated a negative phototropic effect, and the same results have been observed with the isolates used during the past two years. Germ tubes put out by spores show no effect if light is admitted to the germination chamber from a single side, but after a time the mycelium developing from the spores grows away from the source of the light. This may have some effect on the spread of the disease during storage, since the tendency is toward growth into the pile of tubers. In most storage houses this factor is negligible, light being excluded as much as is possible.

### *Temperature*

Temperature has long been recognized as a factor conditioning the development of lesions of silver scurf (Schultz, 1916), but exact data as to the temperature effects have not been published. Excellent equipment has been available for experimental work in this regard. Both electric incubators with thermostatic controls, and modern cold-storage chambers, were used in these studies.

In the incubators, glass culture dishes (moist chambers) were used as containers. The bottoms and the tops of the culture dishes were covered with filter paper, which was moistened from time to time during the storage period so that a high humidity was maintained throughout the trial. Twelve diseased and four healthy tubers were kept in three culture dishes at each temperature. The original lesions were all approximately 1 cm in diameter, and were marked in outline with india ink so that increases in size could be noted. The storage period used was forty-two days. The results are given in table 7.

TABLE 7. NUMBER OF ENLARGED AND OF NEW LESIONS ON IRISH COBBLER TUBERS KEPT IN CULTURE DISHES IN INCUBATORS FOR A PERIOD OF 42 DAYS

| Temperature (F.) | Number of enlarged lesions | Number of new lesions | Number of lesions on check tubers |
|---|---|---|---|
| 37° | 0 | 0 | 0 |
| 43° | 12 | 0 | 0 |
| 48° | 12 | 48 | 0 |
| 54°* | 12 | 63 | 0 |

*At temperatures above 54° up to 75°, the highest temperature used, no counts were made because the spread of the disease was so rapid, and new lesion formation so prominent, that the entire tubers were covered.

At 43° F. sporulation was present, and probably new lesions would have appeared in time; but increase in the size of old lesions amounted only to 2 mm, on the average, for the entire period of forty-two days.

In the cold-storage chamber five temperatures were used, beginning at 33° F. and running to 49° at 4-degree intervals. Constant check on the temperatures showed variations of no more than 2 degrees, these variations being due mainly to the opening of doors of chambers, and lasting for but short periods. Two types of trials were used—one in which the humidity was kept high by storing the tubers in moist chambers, and the other in which the humidity was that of the storage chambers. In the second type, in which peach baskets were used as containers, twenty-five healthy and twenty-five diseased tubers were mixed and placed in storage at each temperature. All lesions were marked as in the preceding experiment. The tubers were examined four times during the winter. Sling-psychrometer readings were taken at weekly intervals. Considerable variation occurred in the moisture present in the atmosphere, so that no one relative humidity can be given for a single chamber. In chambers in which new, and in many cases damp, material was placed in storage, the relative humidity often became comparatively high for short periods.

The results of the latter experiment are given in table 8. The enlargement of the lesions at the 41° and 45° temperatures, and also the new lesions at those temperatures, were probably due to the high degree of humidity found at periods following introduction of new material. The general failure in the development of lesions can be ascribed to drying of the tubers caused by the prevalence of low humidities.

TABLE 8. NUMBER OF ENLARGED AND OF NEW LESIONS ON IRISH COBBLER TUBERS HELD IN PEACH BASKETS IN COLD STORAGE, WINTER OF 1933–34

| Temperature of chamber (F.) | Range of relative humidity (per cent) | Number of enlarged lesions | | | Number of new lesions | | |
|---|---|---|---|---|---|---|---|
| | | On December 10 | On January 10 | On later dates | On December 10 | On January 10 | On later dates |
| 33° | 60–80 | 2 | 0 | 0 | 1 | 0 | 0 |
| 37° | 64–91 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41° | 85–97 | 15 | 0 | 0 | 7 | 0 | 0 |
| 45° | 36–98 | 9 | 0 | 0 | 10 | 0 | 0 |
| 49° | 50–60 | 7 | 0 | 0 | 0 | 0 | 0 |

When moist chambers were used as containers, the tubers were treated as they had been in the experiment in which incubators were used. Only tubers showing small lesions were employed, and the lesions were carefully marked with india ink. At each temperature one moist chamber was filled with tubers having no silver scurf. Care was taken to see that the filter paper used above and below the tubers was moist at all times. Removal of the tops of the chambers may have accounted for dissemination of the spores which caused new lesions. Data were taken on the number of lesions increasing in size and on the number of new lesions formed (table 9). These data show that temperatures below 37° F. are satisfactory for the inhibition of lesion formation and of increase in size of lesions already present.

TABLE 9. EFFECT OF STORAGE TEMPERATURE ON THE NUMBER OF LESIONS INCREASING IN SIZE AND THE NUMBER OF NEW LESIONS FORMED DURING THE STORAGE PERIOD, ON IRISH COBBLER TUBERS IN MOIST CHAMBERS

| Experiment no. | Days in storage | Number of tubers | Temperature of chamber (F.) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 33° | | 37° | | 41° | | 45° | | 49° | |
| | | | Enlarged lesions | New lesions | Enlarged lesions | New lesions | Enlarged lesions | New lesions | Enlarged lesions | New lesions | Enlarged lesions | New lesions |
| | | | Number of lesions | | | | | | | | | |
| 1 | 42 | 8 | 0 | 0 | 2 | 1 | 8 | 16 | 8 | 38 | 8 | 54 |
| | | 4 (check) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 40 | 24 | 0 | 0 | 3 | 2 | 24 | 44 | 24 | 88 | 24 | 146 |
| | | 4 (check) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 41 | 20 | 0 | 0 | 1 | 3 | 20 | 36 | 20 | 79 | 20 | 129 |
| | | 4 (check) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

An experiment was conducted under commercial conditions in cooperation with E. Adams, of Williamson, New York, in which the comparative effects of cellar storage and of cold storage on the development of silver scurf were determined.

In 1933 Mr. Adams' crop of Irish Cobbler potatoes, when dug on September 10, was found to be severely injured by silver scurf. The tubers were cured until October 10, and were then placed in storage. Two cellar storages and a cold storage were available. One of the cellar storages was large, poorly insulated, and subject to wide variations in temperature; the other was small, well insulated, and capable of holding a rather constant temperature through the winter. In the latter cellar the temperature rarely rose above 41° F., which is ordinarily considered a safe potato-storage temperature. The cold storage varied in temperature but little, remaining near 35° F. throughout the storage period.

The four grades used in making counts on the variety test (page 4) were used also in the storage experiment, in determining the amount of silver scurf present at the time when the tubers were stored. The tubers to be used for determining the amount of scurf present were selected by taking a few tubers at random from the bottom, the middle, and the top of crates located at intervals through the cellar or storage house. In the cold-storage house the crates were taken from the front, the center, and the back of the pile, and the counts were kept separate.

Definite increases in the amount of silver scurf could be noted in the cellar storages (table 10). These increases were slightly greater in the large than in the small cellar. There was a significant difference between the cellars and the cold storage, as to the amount of the disease present. Differences in the amount before and after storage could not be detected on tubers kept in cold storage; the size and color of the lesions remained the same as before the storage period. Cold storage seems satisfactory in preventing further spread and enlargement of lesions if the temperature is kept fairly low.

TABLE 10. EFFECT OF DIFFERENT TYPES OF STORAGE ON DEVELOPMENT OF SILVER SCURF

| Storage conditions | Clean | Slight | Moderate | Severe | Number of tubers |
|---|---|---|---|---|---|
| | Per cent of tubers | | | | |
| Before storage | 52.3 | 14.5 | 20.6 | 12.6 | 400 |
| Storage in small cellar | 9.4 | 37.2 | 31.2 | 22.1 | 298 |
| Storage in large cellar | 6.3 | 28.4 | 28.2 | 37.1 | 363 |
| Cold storage: | | | | | |
| Front of pile | 45.5 | 24.2 | 24.2 | 6.0 | 165 |
| Center of pile | 32.6 | 29.3 | 24.8 | 13.3 | 181 |
| Back of pile | 52.7 | 18.5 | 18.5 | 10.2 | 205 |
| Average for cold storage | 43.6 | 24.0 | 22.5 | 9.8 | 551 |

### *Humidity*

The moisture content of the air in the storage chamber is capable of affecting the moisture content of cells of the stored material. Silver scurf affects only the outer cells of the suscept, which are the first affected by the moisture content of the air.

Automatic control of the relative humidity in the atmosphere about the stored tubers was obtained by passing the air through saturated salt solutions. Galvanized containers (figure 5), 16 inches square and 16 inches in height, were used. A sub-bottom was put in each, 2 inches from the

FIGURE 5. APPARATUS USED IN MAINTAINING CONSTANT HUMIDITIES DURING THE STORAGE PERIOD

The motor and pump used to draw the air through the bottles containing the saturated salt solutions are shown, as are also the galvanized containers

bottom, as a support for the tubers. The tubers were stored in a wire basket 10 by 10 by 10 inches in size, so that an air space existed on all sides of the tubers. The top of the container was held in place by bolts so that no air could enter around the edges. Two ¼-inch galvanized connections were placed on opposite sides of the container, one near the top and the other near the bottom. One of these was connected to a suction pump and the other to the salt solutions, so that all the air entering the container first bubbled through the saturated salt solutions. Pinchcocks were used to regulate the amount of air passing through each storage container, so that a known amount of air could be passed through a chamber in a given time. Tests of the air were made at weekly intervals after it had passed through the containers, using the device described by Shippy (1929), which is based on the wet- and dry-bulb-psychrometer principle. The difference in temperature between the wet- and the dry-bulb instrument was converted to relative humidity by the use of the Tycos relative-humidity chart. The salts used were selected from the list given in the international critical tables by Spencer (1926). The amount of material used in the chambers was large, so that at first the moisture content of the air was increased by moisture given off by the tubers. After about five days a constant relative humidity was attained which was at all tests within 1 per cent of that theoretically expected.

In all the work five relative humidities were used, though not the same ones were used in all experiments. The relative humidities used are indicated in tables 11 and 12, with the data resulting. The apparatus (figure 5) was kept in a constant-temperature room at a temperature (50° F.) at which development of silver scurf had been shown to proceed rapidly. Tubers with lesions were marked with india ink so that the margins of the lesions at the time when the tubers were placed in storage could be plainly seen for purposes of taking records. When the tubers were returned to the storage chambers for the subsequent storage periods, the lesions were again outlined with ink.

The same twenty-five tubers that were diseased at the start and the twenty-five that were disease-free at the start were kept in the chambers for 160 days. Records were taken at the end of 41 days, 83 days, 120 days, and 160 days. The data taken at the end of the last two periods were so clearly a repetition of those taken at the end of the second period that they are not presented.

The results of the experiments (table 11) indicate that at 89 per cent relative humidity or below, no new lesions were formed after the tubers had remained in storage long enough for the outer layers to dry; that is, after they had reached an equilibrium with the surrounding air. A change in humidity from 100 to 98 per cent did not seem to influence the development of lesions.

In a second trial, started in the fall of 1934, the air humidities used ranged no lower than 89 per cent. This trial was set up in the same manner as the one described above. The lesions were marked with india ink, as in the preceding case. Tests of the actual humidities showed deviations, from those theoretically expected, to be so small as to be negligible. Both tubers showing lesions at the beginning of the experiment, and those showing no lesions, were used. These were mixed together in the wire basket. The

TABLE 11. EFFECT OF RELATIVE HUMIDITY ON DEVELOPMENT OF NEW LESIONS AND ENLARGEMENT OF OLD LESIONS DURING STORAGE, WHEN ONLY INOCULUM FROM OLD LESIONS WAS PRESENT

| Storage period | | Salt used | Approximate relative humidity (per cent) | Number of tubers stored | Number of new lesions | | Number of enlarged lesions |
|---|---|---|---|---|---|---|---|
| No. | Number of days | | | | On healthy tubers | On diseased tubers | |
| 1st | 41 | $H_2O$ | 100 | 50 | 40 | 22 | 21 |
| 2d | 42 | | | | 14 | 11 | 34 |
| 1st | 41 | $NaH_2PO_4$ | 98 | 50 | 38 | 23 | 20 |
| 2d | 42 | | | | 18 | 12 | 30 |
| 1st | 41 | $K_2SO_4$ | 89 | 50 | 14 | 10 | 13 |
| 2d | 42 | | | | 0 | 0 | 0 |
| 1st | 41 | $NaNO_3$ | 80 | 50 | 8 | 4 | 10 |
| 2d | 42 | | | | 0 | 0 | 0 |
| 1st | 41 | NaCl | 73 | 50 | 6 | 4 | 7 |
| 2d | 42 | | | | 0 | 0 | 0 |

same tubers were kept in storage through two periods, one of 43 days and the other of 42 days. The results of this trial (table 12) show the numbers of enlarged lesions and of new lesions from the time of the start of each period, not through the whole time in storage.

TABLE 12. EFFECT OF RELATIVE HUMIDITY ON DEVELOPMENT OF SILVER-SCURF LESIONS DURING STORAGE, WHEN ONLY INOCULUM FROM OLD LESIONS WAS PRESENT

| Storage period | | Salt used | Approximate relative humidity (per cent) | Tubers healthy at start | | Tubers diseased at start | | Number of enlarged lesions* |
|---|---|---|---|---|---|---|---|---|
| No. | Number of days | | | Total number of tubers | Number of new lesions | Total number of tubers | Number of new lesions | |
| 1st | 43 | $H_2O$ | 100 | 24 | 16 | 35 | 115 | 26 |
| 2d | 42 | | | | 32 | | 67 | 35 |
| 1st | 43 | $NaH_2PO_4$ | 98 | 31 | 14 | 32 | 67 | 31 |
| 2d | 42 | | | | 29 | | 71 | 32 |
| 1st | 43 | $CaSO_4$ | 95 | 32 | 2 | 37 | 31 | 14 |
| 2d | 42 | | | | 14 | | 19 | 37 |
| 1st | 43 | $Na_2SO_4$ | 93 | 30 | 0 | 28 | 27 | 15 |
| 2d | 42 | | | | 3 | | 5 | 18 |
| 1st | 43 | $K_2SO_4$ | 89 | 35 | 0 | 34 | 0 | 12 |
| 2d | 42 | | | | 0 | | 0 | 0 |

*In this column only the lesions that were present at the beginning of the storage experiment were noted through both periods.

From the data presented in table 12 it may be noted that after the first period no new lesions were formed at 89 per cent relative humidity, nor did any of the old lesions increase in size. Lesion enlargement and the formation of new lesions were inhibited below 93 per cent relative humidity. It has been unusual to find sporulation at humidities below 95 per cent. This fact makes probable the supposition that new lesions have originated at the lower humidities from spores present at the time when the tubers were placed in storage. It is even possible that these new lesions were started at that time but did not show macroscopic symptoms.

## CONTROL

### EXCLUSION

Exclusionary measures in regard to *Spondylocladium atrovirens* are difficult of execution. Two factors are responsible for this: the difficulty experienced in recognizing the early symptoms of the disease, and the failure of seed treatments to kill the organism causing the disease.

#### *Seed treatment*

Melhus (1913), and later Schultz (1916), have tried the seed treatments that have proved effective against other tuber diseases. They have tried dry heat, and mercuric chloride and formalin in concentrations and at time intervals that kill the tubers without preventing the fungus from producing spores in ten days after the treatment. In field trials conducted by Schultz, mercuric-chloride treatments were found to be partially successful in reducing the amount of silver scurf if the tubers were planted on virgin soils. Treatments with hot mercuric chloride were more effective than with cold, but the amount of reduction of the disease was not enough to warrant recommendation of this treatment.

In trials with chemicals in the attempt to destroy the fungus on tubers without injuring the tubers for seed purposes, sporulation of the causal organism on treated tubers has been used as a check on the efficiency of the treatments. Sporulation occurs within ten days to two weeks if the tubers are placed in moist chambers at room temperatures. In cases in which the treatment has seemed promising, greenhouse trials have been used in further checking the method.

Mercuric chloride, in concentrations from 1–1000 up to 1–500, has been tried in time intervals until the tubers were killed, both hot and cold treatments being used, without killing the fungus. Other materials that have been tried in a similar manner are formalin, heat, copper sulfate, sodium hypochlorite, carbolic acid, yellow oxide of mercury, crystal violet, malachite green, and a mixture of mercuric cyanide and mercuric chloride. The three last named either reduced the number of spores produced, or completely inhibited spore formation under the conditions of the tests.

Yellow-oxide dip, 2 pounds to 30 gallons, reduced spore formation but did not inhibit it completely. Malachite green, in a 1–100 cold solution applied for five minutes, inhibited spore formation. Mercuric chloride 0.5 gram plus mercuric cyanide 0.5 gram, to 1000 cc of water, applied for five minutes, inhibited spore formation. All tubers produced sprouts after these treatments.

Malachite-green treatments as tried in the greenhouse have not been successful in inhibiting lesion formation when diseased tubers have been used as seed. Results from twelve pots in the greenhouse showed fairly good control and no injury with mercuric chloride and mercuric cyanide used at the rate of 0.5 gram of each material in a liter of water in which the tubers were soaked for twenty minutes. One of the harvested tubers in each of three of the pots was affected with scurf; those in the other nine pots were healthy. No growth of the fungus was obained from twenty-four plantings made from treated tubers.

### *Soil treatment*

Yellow-oxide treatments have not been tried in the greenhouse, but counts have been made of tubers grown on muck soil to which 11.5 pounds of yellow oxide to the acre was added, as compared with tubers from untreated plots.[5] The counts are given in percentages in table 13. These tubers had been kept in storage long enough for all the spots to become easily recognizable.

TABLE 13. PERCENTAGES OF POTATOES AFFECTED BY SILVER SCURF ON PLOTS TO WHICH YELLOW OXIDE OF MERCURY HAD BEEN ADDED AT THE RATE OF 11.5 POUNDS TO THE ACRE

| | Plots treated with yellow oxide of mercury | Check plots |
|---|---|---|
| | Per cent of potatoes affected | |
| Potatoes silver-scurf-free | 90 | 62 |
| Amount of disease present: | | |
| Slight | 8 | 18 |
| Moderate | 2 | 8 |
| Severe | 0 | 12 |
| Total silver scurf | 10 | 38 |

In this single instance, yellow oxide showed some promise for use as a soil treatment.

## PROTECTION

Protection seems applicable only to tubers under storage conditions. Manipulation of the temperature and the relative humidity of the storage house shows much promise, and it is believed that satisfactory control of the spread of the disease under storage conditions can be secured in this manner.

Early digging under field conditions shows promise, in preventing at least a large number of the lesions from forming before the tubers are placed in storage.

## IMMUNIZATION

The literature contains no reference to immune varieties of potatoes. Preliminary counts on certain varieties (table 1, page 4) indicate that some are more susceptible than others to silver scurf.

[5] From an experiment on scab control conducted by C. A. Taylor, assistant in the Department of Plant Pathology, Cornell University.

SUMMARY

The white potato, *Solanum tuberosum,* is probably the only plant susceptible to silver scurf, and this plant is affected only on the fleshy tubers. Inoculation work, as well as field counts, indicates that tubers become susceptible at or near maturity in the soil, and are highly susceptible during the storage period. Certain varieties are more susceptible than others.

Symptoms serve adequately to separate this disease from other diseases of the potato tuber. Signs — conidia and conidiophores — have diagnostic value under moist warm storage conditions.

Invasion by the fungus is confined entirely to the phellem layers. Penetration of the living cells below the phellem has not been observed. The fungus is capable of loosening the suberized cells from which it takes its food, causing them to slough off.

Studies of the growth of the fungus in culture have shown growth rates, in regard to the effect of humidity and temperature, that closely parallel growth under similar conditions on the potato. The fungus is capable of growth in culture over a wide pH range.

During storage, invasion by the fungus of tissue not already affected is dependent on proper conditions of humidity and temperature. Lesion inception and enlargement are inhibited at humidities below 90 per cent and at temperatures below 37° F.

Seed treatments have not been entirely satisfactory, but some promise has been shown by malachite green and a mixture of mercuric cyanide and mercuric chloride. Yellow oxide of mercury used as a soil treatment may also be valuable in preventing the disease in the field.

There are indications that control of the disease can be secured by prompt digging of the tubers at maturity.

REFERENCES

APPEL, OTTO, AND LAUBERT, R. Die Konidienform und die pathologische Bedeutung des Kartoffelpilzes *Phellomyces sclerotiophorus* Frank. Kais. Biol. Anst. Land- u. Forstw. Arb. **5**: 435–441. 1907.

ARTSCHWAGER, ERNST. Studies on the potato tuber. Journ. agr. research **27**: 809–836. 1924.

BAILEY, F. D. Notes on potato diseases from the Northwest. Phytopath. **4**: 321–322. 1914.

BRITTLEBANK, C. C. Potato diseases—the danger of importation. Victoria Agr. Dept. Journ. **12** (1914): 400–403. 1915.

CLINTON, G. P. Scurf, *Spondylocladium atrovirens* Harz. *In* Notes on fungous diseases, etc., for 1907. Connecticut Agr. Exp. Sta. Repts. **31–32**: 357–359. 1908.

CRÉPIN, CH. Dartrose (*Vermicularia varians* Ducomet) et gale argentée (*Spondylocladium atrovirens* Harz) du tubercule de pomme de terre. Rev. path. vég. et ent. agr. **10**: 63–66. 1923.

DEAN, A. L. Root-observation boxes. Phytopath. **19**: 407–412. 1929.

DICKSON, B. T. The "black dot" disease of potato. Phytopath. **16**: 23–40. 1926.

EICHINGER, A. Zur Kenntnis einiger Schalenpilze der Kartoffel. Ann. mycol. **7**: 356–364. 1909.

FRANK, A. B. Die Fleckenkrankheit der Kartoffelschale mit dem *Phellomyces sclerotiophorus* Frank. *In* Kampfbuch gegen die Schädlinge unserer Feldfrüchte, p. 182–185. 1897.

———— Die Phellomyces-Fäule. *In* Untersuchungen über die verschiedenen Erreger der Kartoffelfäule. Deut. Bot. Gesell. Ber. **16**: 280–281. 1898.

HARZ, C. O. Einige neue Hyphomyceten Berlin's und Wien's nebst Beiträgen zur Systematik derselben. Soc. Imp. Nat. Moscou. Bul. **44**[1,2]: 88–147. (Reference on p. 129–130.) 1871.

HUSZ, BÉLA. Ueber die Zugehörigkeit von *Phellomyces sclerotiophorus* Frank und dessen Unterscheidung von *Spondylocladium atrovirens* Harz. Ztschr. Pflanzenkrank. u. Pflanzenschutz **44**: 186–191. 1934.

JOHNSON, T. *Phellomyces sclerotiophorus*, Frank: a cause of potato scab and dry rot. Roy. Dublin Soc. Econ. proc. **1** (1899–1909): 161–166. 1903.

LINDAU, G. Spondylocladium Mart. *In* Engler and Prantl's Die Natürlichen Pflanzenfamilien **1**[1]: 476–480. 1900.

MASSEE, G. Plant diseases.—IX. Dry scab of potatoes, *Spondylocladium atrovirens* Harz. Roy. Bot. Gard. Kew. Bul. misc. inform. **1909**: 16–18. 1909.

———— Dry scab of potatoes. *In* Diseases of cultivated plants and trees, p. 478–480. 1910.

MELHUS, I. E. Silver scurf, a disease of the potato. *In* Miscellaneous papers. U. S. Plant Indus. Bur. Circ. 127: 15–24. 1913.

O'GARA, P. J. Occurrence of silver scurf of potatoes in the Salt Lake Valley, Utah. Science **41**: 131–132. 1915.

PETHYBRIDGE, G. H. *Colletotrichum tabificum*. *In* Notes on some saprophytic species of fungi, associated with diseased potato plants and tubers. Brit. Mycol. Soc. Trans. **6**: 107–111. 1920.

REES, H. L. Silver scurf disease. *In* Diseases of potatoes. Western Washington Exp. Sta. Monthly bul. **1**[6]: 15–16. 1914.

RIDGWAY, ROBERT. Color standards and color nomenclature. 1912.

SCHULTZ, EUGENE S. Silver-scurf of the Irish potato caused by *Spondylocladium atrovirens*. Journ. agr. research **6**: 339–350. 1916.

SHAW, LUTHER. Intercellular humidity in relation to fire-blight susceptibility in apple and pear. Cornell Univ. Agr. Exp. Sta. Memoir 181: 1–40. 1935.

SHIPPY, WILLIAM. An inexpensive and quickly made instrument for testing relative humidity. Bot. gaz. **87**: 152–156. 1929.

———— Influence of environment on the callusing of apple cuttings and grafts. Amer. journ. bot. **17**: 290–327. 1930.

SMITH, ANNIE LORRAIN, AND REA, CARLETON. *Phellomyces sclerotiophorus* Frank. *In* Fungi new to Britain. Brit. Mycol. Soc. Trans. **2** (1902–1906) : 59. 1903.

SPENCER, HUGH M. Laboratory methods for maintaining constant humidity. International critical tables of numerical data, physics, chemistry and technology, **1** : 67–68. 1926.

STEVENS, NEIL E. A method for studying the humidity relations of fungi in culture. Phytopath. **6** : 428–432. 1916.

TAUBENHAUS, J. J. A contribution to our knowledge of silver scurf (*Spondylocladium atrovirens* Harz) of the white potato. New York Bot. Gard. Memoirs **6** : 549–560. 1916.

WILSON, JAMES K. Calcium hypochlorite as a seed sterilizer. Amer. journ. bot. **2** : 420–427. 1915.